

SUBBAND ENERGY DETECTION IN PASSIVE ARRAY PROCESSING

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ABSTRACT

Broadband processing is an important part of the Navy's current and future SONAR systems. This paper provides an introduction to a new class of passive broadband processing algorithms, Subband Energy Detection (SED), which includes both Subband Peak Energy Detection (SPED) and Subband Extrema Energy Detection (SEED). It will be shown that SED has several performance advantages over Conventional Energy Detection (CED), also known as Linear Rectify (LR).

SED exploits the spatial coherence of the signal's local maxima ("peaks") and minima ("valleys") compared to the randomness of noise to increase the quality of the broadband processing display. Instead of summing the energy in each single beam over the frequency band, SED sums the energy of the peaks and valleys in the azimuth spectrum for each frequency bin.

The objective of this paper is to examine the theory, advantages, and limitations of Subband Energy Detection. In doing so, we will first give an overview of broadband processing and discuss energy detection theory. We will then describe the theory of both CED and SED. Processed data from both sets of algorithms will then be analyzed to uncover the relative advantages and disadvantages of each method.

1. INTRODUCTION

For a single time scan, the output of the beamformer is a 2dimensional matrix in frequency and azimuth known as a FRAZ (FRequency AZimuth). A 2-dimensional FRAZ cell contains a measurement of the energy for each azimuthal and frequency bin. A typical

example FRAZ is shown in Fig. 1a. Broadband processing methods collapse the FRAZ over frequency to a single dimension, azimuth. The result is a bearing-time record (BTR) display, Fig. 1b, which allows the operators to detect contacts and provides a high level of situational awareness.

In the past, broadband detection methods such as CED and cross-correlation (CC) have provided this critical function while attempting to maximize the operator's detection ability. Recently, a new class of broadband detection methods, Subband Energy Detection (SED), has been developed and has emerged as an accepted alternative [1].

2. ENERGY DETECTION

The goal of energy detection methods is to create an estimate of the probability of detection of an acoustic source at a given time and location. This requires the reduction of the beamformer output, which is a function of time, azimuth, and frequency into the time-azimuth plane. As a result, both CED and SED collapse the beamformer output over frequency but each takes a different approach.

2.1 Acoustic Environment

The ocean acoustic environment consists of acoustic energy from both contact signals and random noise. This noise field is the result of a large number of factors such as wave action, seismic events, marine life, and distant shipping activity.

Since this noise field is a collection of sources, it also has a certain level of directionality associated with it. The attenuation factor for acoustic waves is also larger for higher frequencies. The result is a noise field dominated in power by low frequency spectral content and significantly less high frequency content.

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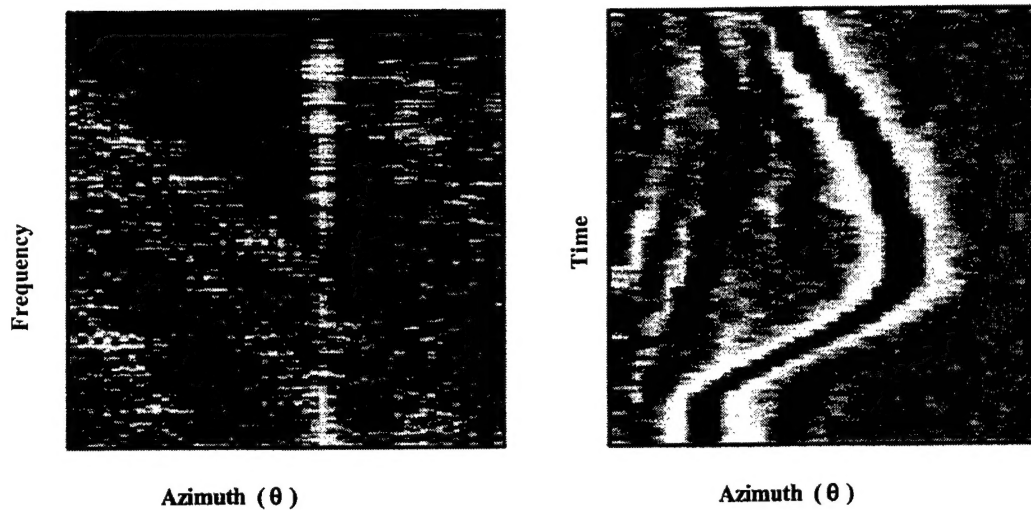


Figure 1: Broadband Processing Methodology (A) FRAZ- FFrequency Azimuth plot for a single time scan, (B) BTR- Bearing Time Record Display that is the final broadband display.

2.2 Normalization

Due to the nature of the noise field, energy detection methods typically utilize a noise floor estimate. This is done since signal to noise ratio (SNR) is used as the energy value. It has been shown that the use of SNR versus raw signal typically increases the performance of the algorithm. Simply summing the raw energy in each frequency bin ignores the fact that low frequencies dominate the energy distribution. Doing so may prevent the detection of primarily high frequency contacts.

Energy detection methods with noise floor estimation have demonstrated good detection capability including the detection of low SNR contacts (i.e. signals quieter than the average noise floor) [2]. In part, this detection capability benefits from two primary concepts: spatial coherence and sidelobe rejection.

2.3 Energy Detection Concepts

Spatial coherence is defined as the alignment of distinct frequency components of a contact signal. Since the frequency components spatially align, they strengthen the energy estimate and increase the detectability of contact signals over random noise.

Energy detection methods also provide inherent sidelobe rejection. The reason for this is related to the beamforming process. Beamforming spatially filters the elemental array timeseries. Ideally, there is a unity gain in the look direction and a zero gain in all others. Realistically, the array gain pattern, or beam pattern includes a mainlobe of a certain width and several sidelobes which allow noise and interferer energy to leak into the beam measurement.

At high frequencies, the beam pattern has a narrow mainlobe and many narrow sidelobes. As the frequency is reduced, the lobe width increases and the location of the sidelobe peaks shift in azimuth. The result is that for a single beam measurement, the mainlobe peaks line up in the same azimuth bin for all frequencies while sidelobe peaks spatially shift and will not line up over the frequency range. This mitigates the effect of sidelobe energy leakage.

3. CONVENTIONAL ED

Conventional Energy Detection (CED), also known as Linear Rectify (LR), is a traditional energy detection method. CED will be utilized as a baseline for evaluating Subband Energy Detection (SED) performance.

3.1 CED Principles of Operation

CED starts with a FRAZ for a single time scan and processes each azimuth bin, Fig 2a. A single azimuth bin contains a frequency spectrum of signal plus noise, as seen in Fig. 2b. As mentioned above, the next step is to perform a noise estimate. The method used by CED for estimating the noise floor applies a median filter in frequency and azimuth.

CED then calculates the signal to noise ratio (SNR) by dividing the beamformer output (signal plus noise), Fig. 2b, by the noise floor estimate, Fig 2c. Finally, it calculates an energy estimate by summing the SNR values in all desired frequency bins for the single azimuth bin. This process is repeated for each azimuth bin and

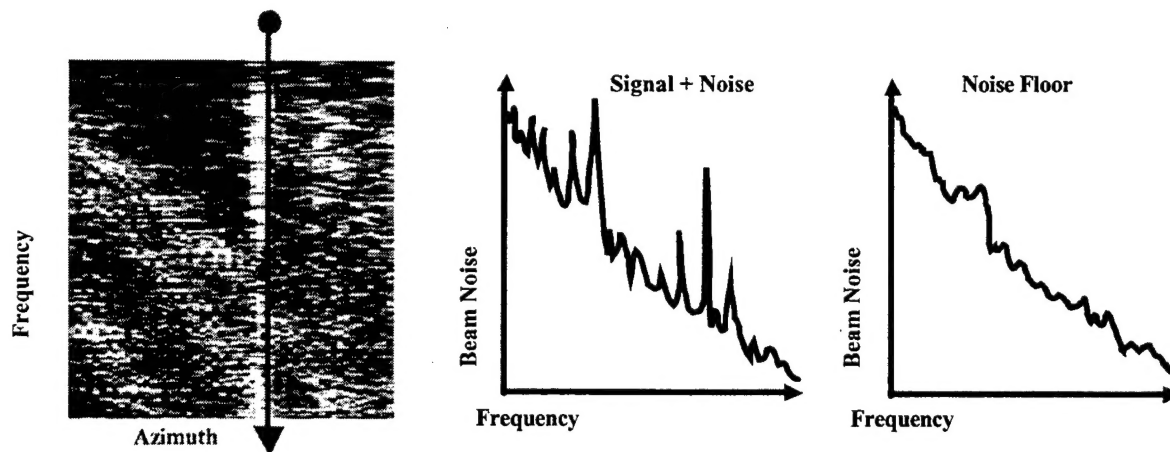


Figure 2: Conventional Energy Detection (A) FRAZ display with arrow showing a single azimuth bin, (B) Frequency spectrum of the measured signal plus noise for a single azimuth bin, (C) Frequency spectrum of the normalized noise estimate.

every time scan to produce a BTR display which is used to detect acoustic contacts.

3.2 CED Performance

CED has been shown to provide optimal single signal detection in uncorrelated noise fields. The theoretical minimum detectable level (MDL) of CED for this case is better than that of the SED algorithms presented next. As such, CED provides raw optimum detection ability for isolated signals.

There is, however, one major limitation of CED. CED produces wider contact traces due to the limited bearing resolution. As a result, CED is not optimal for real world acoustic environments with multiple signals. This produces BTR displays with wide, blurry traces for loud contacts.

The detection ability of the system for cluttered, real world acoustic noise environments is impaired since the wide, blurry traces may suppress nearby, quieter contacts. So, despite the theoretical MDL advantage of CED for isolated signals, SED has an overall detection advantage in clutter due to the increased bearing resolution and narrower contact traces. This can be seen in the results in Fig. 5 and will be discussed further later.

4. SUBBAND ED

Subband Energy Detection (SED) is a new class of energy detection methods. These algorithms have gained acceptance and are currently used in real world SONAR systems.

4.1 SED Principles of Operation

SED starts with the same FRAZ information as CED. However, instead of looking at the frequency spectrum in a single beam, SED looks at the azimuth spectrum for a single frequency bin, Fig 3a. SED finds the locations of all “peaks” and “valleys” in the azimuth spectrum for each frequency bin. An example azimuth spectrum is seen in Fig. 3b. A peak is simply a local maximum in azimuth and a valley is a local minimum in azimuth. These peaks and valleys are then used to generate an energy estimate using one of several algorithms. Fig. 4 shows BTRs for a real acoustic data set processed by each of the four primary SED algorithms.

4.2 SPED and SEED

There are two fundamental classes of Subband ED algorithms: Subband Peak Energy Detection (SPED) and Subband Extrema Energy Detection (SEED). In addition, each class has at least one version from two modes: Clutter Suppress (CS) and Energy Detection (ED).

SPED utilizes only the peak information to estimate the detection probability. It examines the azimuth spectrum for every frequency bin and locates the peaks. For each azimuth bin containing a peak, a value, or “reward”, will be added to the energy estimate for that azimuth bin. The actual value of the reward will depend on the mode of the algorithm (i.e. CS or ED). This is repeated for each frequency bin.

Unlike with CED processing, if the bin does not contain a peak then SPED will not add to the energy estimate for that azimuth. In other words, SPED sums only the energy at the peaks.

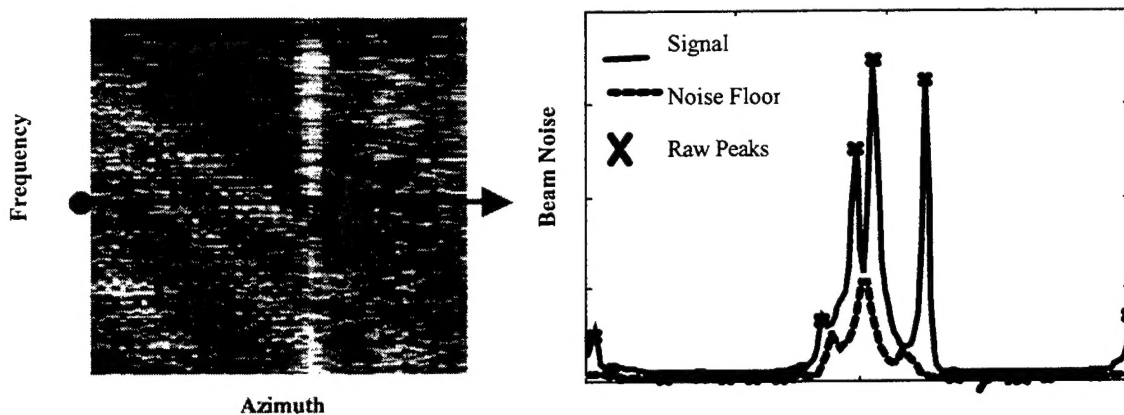


Figure 3: Subband Energy Detection (A) FRAZ display with arrow showing a single frequency bin, (B) Azimuth spectrum of a single frequency bin showing the signal peaks and the noise floor.

Subband Extrema Energy Detection utilizes both peak and valley information to estimate the detection probability. Like SPED, it will add a reward for peaks. In addition, it will also subtract a value, or assess a “penalty” for any valley that is located in an azimuth bin.

4.3 CS and ED Modes

The clutter suppress mode (CS) assigns a reward and penalty of unity for each peak and valley. This mode can be thought of as a histogram and basically counts the number of peaks (and, in the case of SEED, subtracts the number of valleys). It does not attempt to account for the magnitudes of these peaks and valleys. As a result, the CS mode does not require noise floor estimation. This method works well with broadband contacts but poorly with contacts containing only a few loud frequency components.

The energy detect mode assigns a reward and penalty based on signal to noise ratio. This requires the calculation of a noise estimate. The reward is simply the measured beam noise (signal plus noise) divided by the noise estimate. The penalty calculation is less straightforward and is an area of current research [3,4,5].

The noise estimate typically used is a complex algorithm that averages over time, clips tonals, applies a smoothing filter, and then takes the quiet value in an azimuth sector as the noise floor.

4.4 SED Theory

Peaks and valleys occur due to both contact signals and random noise. Even when the average noise floor is greater than the contact, the fluctuations of the

noise may cause it to drop below the contact signal. When this happens, there is a peak due to the contact signal.

In one frequency bin of the beam noise versus azimuth spectrum, there may be several peaks due to the signal but still many more due to noise. Although noise peaks outnumber signal peaks, low SNR contacts may still be detected because peaks due to contact signals will have spatial coherence (i.e. occur in the same azimuth bin for each frequency) while noise peaks will not. As a result, these signal peaks add “constructively” when summed over the entire range of frequency bins.

SED is often referred to as a “peak-picking” method. Instead of summing the energy in every frequency bin, SED sums only the energy values for the bins that contain extrema. In effect, this detects only the peak of the mainlobe, reduces the width of the contact traces, and provides increased spatial resolution of the BTR display. This serves to provide SED with a detection advantage over CED in cluttered environments since quiet contacts are no longer hidden by nearby louder ones.

5. RESULTS

Fig. 5 shows four acoustic data sets processed by both CED and SEED CS. The first example (on the left) shows comparable detection ability. Despite the better theoretical MDL of CED for isolated targets, this and most other real data sets show no appreciable difference in detection ability.

The peak-picking provides SEED CS with sharper, more clearly defined contact traces as can be seen

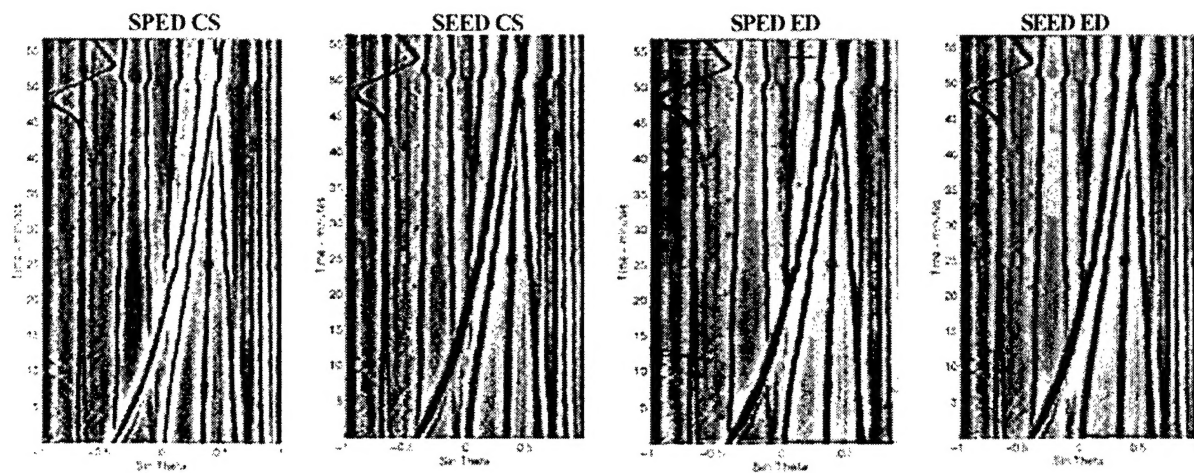


Figure 4: BTR displays for a real acoustic data set processed by several Subband ED algorithms (A) SPED CS, (B) SEED CS, (C) SPED ED, (D) SEED ED

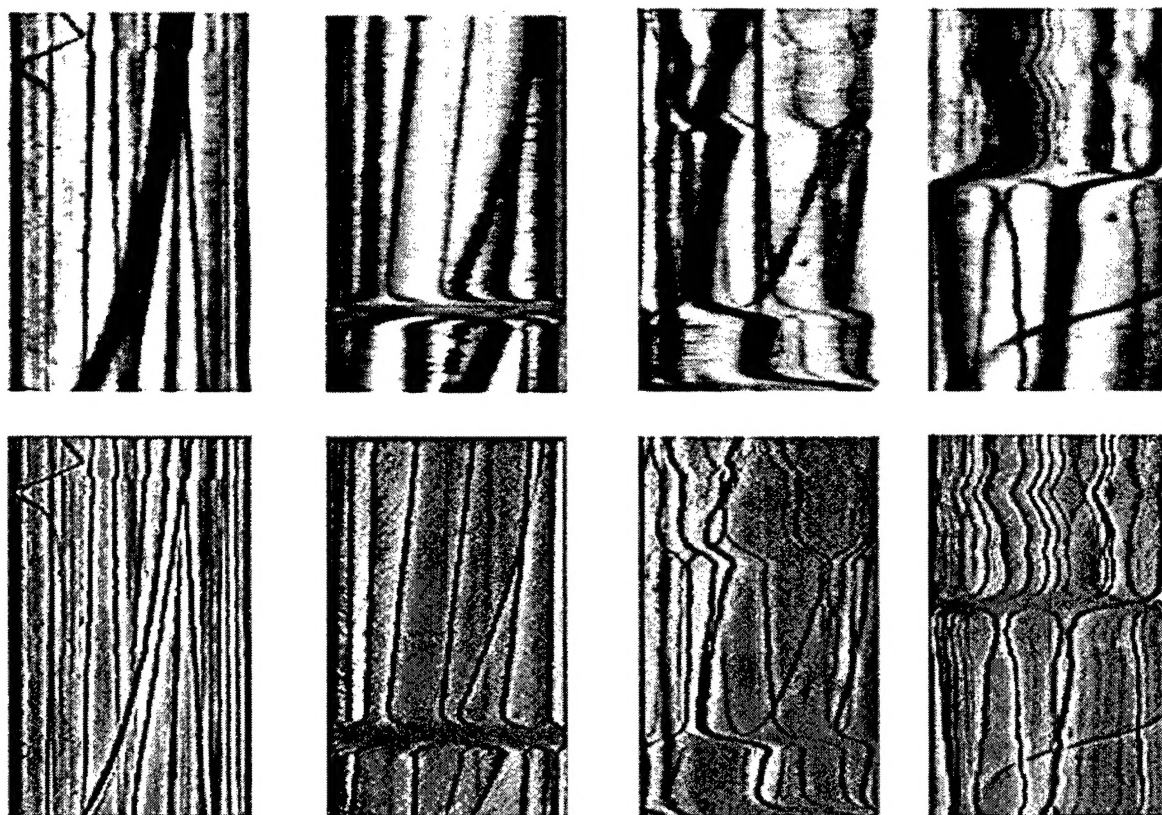


Figure 5: BTR displays for Conventional ED (top row) and Subband Extrema Energy Detection- Clutter Suppress Mode, SEED CS, (bottom row) for four real acoustic data sets.

in the second example from the left. This reduces the 'blacked out' areas resulting from loud contacts. In this example, the increased spatial resolution does not improve performance substantially since both grams contain all traces.

In the third example from the left, which shows a cluttered environment, the increased spatial resolution does provide a significant detection advantage. Traces that are blurred together in the CED gram can clearly be seen in the SEED CS gram.

The final example again shows the detection advantage of SED in cluttered noise environments. It also shows comparable detection performance for the contact of interest, the high bearing rate trace at the bottom.

6. SUMMARY

This paper has compared the theory and results of both Conventional Energy Detection and Subband Energy Detection. The results have shown that SED provides narrower contact traces and increased bearing resolution since only the energy of the peaks and valleys are summed. There is also reduced smearing of acoustic energy over large azimuths and an improved ability to detect nearby contacts. Additionally, despite a lower theoretical MDL for isolated signals, SED displays a significant detection advantage in real world (cluttered) acoustic environments. The overall conclusion is that Subband Energy Detection is an important broadband processing method that provides increased performance to Navy SONAR systems.

7. REFERENCES

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